



The Effect of Particle Dispersion due to Mixing Speed on Spent Coffee Ground Composites

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ABSTRACT

Composites using bio-materials with unique properties, such as spent coffee ground were developed for composite fillers. This study was conducted to produce samples under various mixing speed conditions. This study also determined effect of mixing speeds on particle homogeneity as well as composite dispersion in the final product. The composite dispersion was determined by an index based on a standard deviation of free-path spacing of filler particles using a digital microscope. Results showed that when using high-speed mixing, particle tends to agglomerate with particle clumps. We also obtained that faster mixing speed results more homogeneous mixture compared to slower speed. In short, slower speed can reach similar result in homogeneity levels, but it would require longer time for the mixing process.

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1. INTRODUCTION

Composites have been widely applied and developed in wide range of uses due to their properties and flexibility during the manufacturing process (Bale *et al.*, 2019). Composites also have been studied in various fields, including the use for material fillers (Mavhungu *et al.*, 2017; Wu, 2015). One of the products that can be used as a composite is spent coffee grounds (SCG).

SCG particles are an alternative for materials that could be recycled and re-used for its availability. Approximately 314,400 tons of coffee are consumed by Indonesian and most of their wastes are disposed and unlikely to be re-used (Zarrinbakhsh *et al.*, 2016). Development of these materials into a useful resource would be an advancement in the renewable material department.

Application of SCG has been well-documented and reported for special purposes, such as odor removers (Woo *et al.*, 2017), a water remediator (Chavan *et al.*, 2016), or a colorant. SCG also could be used for fillers. Further, we can manufacture SCG based on how we utilize them. In this study, SCG was produced using hand lay-up since this method is one of the most basic methods for manufacturing composites (Mohanty *et al.*, 2018). Hand lay-up has high adaptability (Elkington *et al.*, 2015) and applying the right amount of variables is possible. Its flexibility in the manufacturing process would help it be less complex in the observation of filler particles (Mohanty *et al.*, 2018). For understanding the effect of specific variables on the manufacturing process, we limited variables.

To be applied as filler, SCG particle distribution is a critical variable, influencing properties of the composite. A more homogenized distribution of the fillers would contribute in increasing mechanical

properties, heat, and electrical distribution and therefore change the performance of the final composite (Oh *et al.*, 1998; Prabu *et al.*, 2006).

The variety from the dispersion of particles may be attributed to properties of matrix, particle sizes, particle volume (or weight fraction), and its processing steps that are required. This includes chemical and physical mechanisms that influence the particles' interface. With the multicomponent nature of the system, it is difficult to identify the particular process controlling the observed effects (Barabash *et al.*, 2018). Therefore, mixing techniques which has a significant role in industrial process of particle composites would suit in an empirical study.

The mixing of matrix and particles from aggregates/agglomerates and continued through free dispersion would be that of fluid-solid material mix and would adhere to matrix fluid principles. This would be in hand by applying computational fluid dynamics as a main method in fundamental research for predicting local fluid dynamics. Due to the complexity of dispersion and the unsteadiness of fluid flow, however, simulations in that regard are less desired (Barabash *et al.*, 2018).

Indicators for a successful solid-fluid mixture would be done in the complete suspension. This requires a minimum mixing impeller speed where an under-speed would result in an unsuspended mixture that would have no effect in observation (Kraume, 1992). With the increases in higher impeller speed, the mixing time would decrease but this puts the system in a need of extra energy spent for solid-liquid interface and less energy for mixing (Bujalski *et al.*, 1999; Rao and Joshi, 1988). Impeller speed employed is determined with respect to the characteristics of matrix to obtain complete suspension. In this study, it would

be established as a variable, as mixing speed would be a sensible standard of comparison.

The dispersions of materials would lead to characterize the microstructural and quantifying the homogeneity. This has been developed by several researches through microscopy analyses (Luo and Koo, 2007; Paciornik and D'almeida, 2009; Yakaboylu and Sabolsky, 2017). The quantitative measurement indexes in this case pertains to a study of composites, considering the pattern of microstructure. Yakaboylu's method quantifies the dispersion and models his research mainly on binary composites while limiting factors that reduces accuracy and therefore a good option to employ. By developing the indexes, a certain trend in determining good dispersion standard of particles could be developed and quantified.

2. MATERIALS AND METHODS

The method of manufacturing samples was described in the following. Waste spent coffee grounds were collected from local coffee shops and its humidity decreased to under 5% by oven drying. The grounds are then processed using mortar and pestle for decreasing clumps. Resultant was filtered with sieves of mesh 80 as this particle size ensues good mechanical properties (Fu et al., 2008). Density measurement of SCG is 514 kg/m³ using ASTM D6683-03. The resin type utilized was ETERSET 2504 APT with a viscosity (ranging from 300 to 600 cps) and density of 1120 kg/m³ (de Melo et al., 2014). The fractions of solids and resin in this case is 40 and 60 wt%, respectively, and should be considered when determining the mixing

speed. Kraume developed mixing times of over 100 s for viscosities of 12 cps with rotational speeds ranging from 400 to 800 rpm to achieve complete suspension. Thus, mixing speed of the WESTLAKE ZHX-13 drilling machine was used (515, 915, and 1430 rpm) to rotate a general dual blade paddle of 5 cm in length for one minute. The suspension was then degassed in a vacuum chamber with a pressure of negative 90 kPa. The time of degassing was more than 7.5 minutes (Kraume, 1992). Mixture was applied with hardener and poured into 31 cm x 31 cm x 0.3 cm mold which includes fiber glass. The mixture was kept to be hardened and then cured in 60°C where it would be continued until total curing process. Several microscopy samples were taken and processed referring to Yakaboylu's method. The composite panel was analyzed by its microstructure using a digital microscope for its homogeneity. Based on its free-path spacing, a grid was developed upon its microstructure of binary image, processed using an ImageJ software and determined of its scaling in micrometers where it would be further processed. Each line is determined:

$$\overline{X}_{h1} = \frac{1}{n} \sum_{i=1}^n X_i; \overline{X}_{v1} = \frac{1}{n} \sum_{i=1}^n X_i; \quad (1)$$

where *h* and *v* are the abbreviations of horizontal and vertical lines, respectively. *n* is the number of free path spacing on a specific line drawn. **Figure 1** displays a horizontal and vertical X_1 . These X values as the equation (1) suggested are summed from this spacing to obtain \overline{X}_{h1} from the horizontal X_1 and likewise for \overline{X}_{v1} the vertical X_1 .

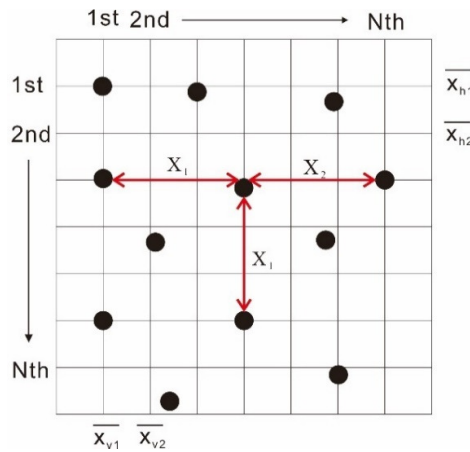


Figure 1. Schematic diagram of free-path spacing image analysis. Black dots represent the particles in the sample.

The arithmetic mean (\bar{X}) and standard deviation (s) is then continued to be calculated:

$$\bar{X} = \frac{(\bar{X}_{h1} + \bar{X}_{h2} + \dots + \bar{X}_{hN}) + (\bar{X}_{v1} + \bar{X}_{v2} + \dots + \bar{X}_{vN})}{2N} \quad (2)$$

where values of X_h and X_v are derived from equation (1). Homogeneity is considered when the arithmetic mean values of the free spacing is similar in each line analyzed. The values on each line has varieties and the standard deviation is analyzed through \bar{X} of equation (2), thus the C_v or the coefficient of variation is determined to access variety of free path spacing for $2N$ lines. C_v could be written as:

$$C_v = \left(\frac{s}{\bar{X}}\right) \quad (3)$$

The value of $C_v = 0$ is determined to be perfectly homogeneous composite material, and their arithmetic mean values on each line are the same. The increases in agglomeration would increase the value of inhomogeneity. Indeed, the C_v value would also increase.

3. RESULTS AND DISCUSSION

The finished square panel resulted in a dark brown board. Panel observation is conducted at three main points on the material. From cartesian coordinate point of

view in centimeters where the bottom left corner is the (0, 0) point, we observed point 1 (7 cm, 5 cm), point 2 (27 cm, 15 cm), and point 3 (15 cm, 25 cm) as indicated in **Figure 2**. The experimental results show C_v of the three respective points on the plane.

The binary images developed from the digital microscope has shown excellent particle dispersion, representing the microstructure of the composite. Coffee particles tended to agglomerate in the certain parts. These agglomerations develop on certain areas and leave voidages in the matrix, informing no or less number of particles in some areas.

In the limited time of mixing, low-speed homogeneity of the particles would not have the most stable results as different points of the structure have different homogeneities indexes (see **Table 1**). The samples for lower mixing speed (*i.e.*, 515 rpm) had more varieties of dispersion. Increases in the mixing speed can allow increases in the the homogeneity index. The highest mixing speed (*i.e.*, 1420 rpm) has less variation between the samples. Homogeneity on the highest speed were the most stable in terms of results between the points in homogeneity index among the other mixing speeds.

To confirm the analysis, all data were categorized based on the homogeneity index (Yakaboğlu and Sabolsky, 2017). The degree of dispersion can be classified into high level of homogeneity (between 0 and 0.25), moderate level of homogeneity (between 0.25 and 0.40), low level of homogeneity (between 0.40 and 0.60) and very low level of homogeneity (more than 0.60). In the study, all the average results

were located in the “high” region of dispersion. Therefore, it can be concluded that the samples were in the high degree of distribution. However, there were large variations within the microstructure with mixing speeds of 415 and 915 rpm, indicating a low distribution of particle dispersion on specific points of the microstructure.

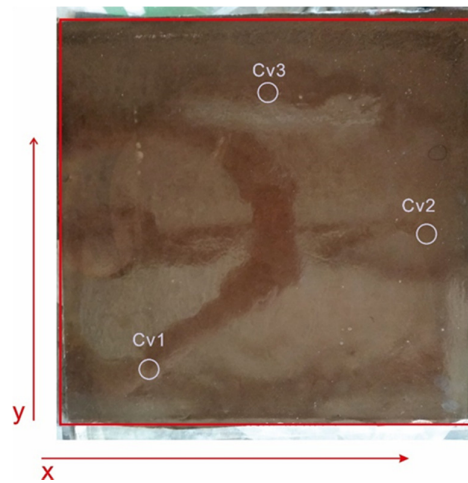


Figure 2. SCG composite panel using 515 rpm mixing speed and points of interest in microstructure image processing.

As the densities of the solid and liquid materials were determined to be lower for the solids, the solids were considered to be neutrally buoyant. This would result in the need of a high suspension velocity to disperse the particles radially. Dispersing these particles rapidly would be essentially dispel the local accumulations (Roni et al., 2019). This principle signifies that the speed of mixing would inherently affect the dispersion of the solid (Bujalski et al., 1999; Rao and Joshi, 1988). We could achieve faster homogeneity with higher mixing speeds. A lower mixing speed would require longer mixing time. Hence, the more variety in homogeneity factors would result the lower speed mixed composites.

Figure 3 shows significant differences in the microstructure of the three different speeds. The result of lower speed is dominated by smaller clumps of particles. Agglomeration and combined particles (large clusters) were found, informing incomplete dispersion. The higher aggregation and combined particles increases, and they appear in the microstructure. The lower mixing speed has a different formation of solid-liquid interface compared to the higher mixing speed. In fact, the interface will create different types of composite (Kraume, 1992; Fu et al., 2008; Van de Velde and Kiekens, 1999) since it depends on various factors, such as compaction of molecular shape, surface free energy, chemical potential, and molecular

composition among others. However, these factors are not comparable to a pile-up particles in the suspension of the mixture (Uhlmann *et al.*, 1964). As the higher speeds develop more clumps between the particles, it does not necessarily suggest a decrease in surface area contact between the matrix and the particle. Forces such as capillary forces and other various forces such as adhesion will take part. But, ultimately for a solid-liquid mixture, the contact angle, dynamic conditions, and surface roughness would become the main parameters in the surface tension (Roni *et al.*, 2019).

Higher mixing speed allows more energy in a unit area of free surface. The surface tension or surface energy will bring positive impact on cohesion (Roni *et al.*, 2019). And, this cohesion affects surface areas and gives benefit on maintaining a homogenous distribution of particle mixture from various points in the final structure. High levels of Cv on many points of a microstructure would give a good homogeneity of the overall structure.

Table 1. Homogeneity of three different areas of SCG composite.

Mixing speeds	Cv1	Cv2	Cv3	AVG
515 RPM	0.145	0.259	0.189	0.198
915 RPM	0.199	0.283	0.222	0.235
1430 RPM	0.198	0.195	0.183	0.192

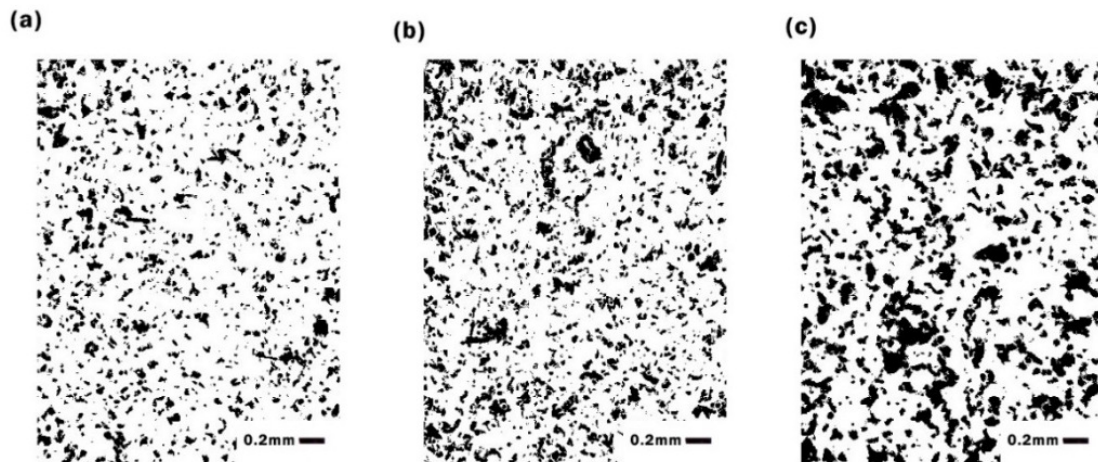


Figure 3. Typical binary microstructure microscopy of SCG composites with mixing speeds of (a) 515, (b) 915, and (c) 1430 rpm.

4. CONCLUSION

Optical microscope completed with image processing software is effective to determine the SCG dispersion. To confirm the analysis, this study varied the samples, specifically the mixing speed and the particle homogeneity. The results showed that the high-speed mixing can allow the highest

homogeneity results. On the contrary, low speeds have given almost the same homogeneity levels, but the dispersion type of sample depends on the position in the sample. The high-speed mixing is also the best since it can permit the dispersion for shorter time and develop better wetting condition between matrix and filler.

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6. AUTHORS' NOTE

The author(s) declare(s) that there is no conflict of interest regarding the publication of this article. Authors confirmed that the data and the paper are free of plagiarism.

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